# JUVENILE FISH FACILITY RAW WATER SUPPLY AND DRAIN DESIGN

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## INTRODUCTION

One part of NWW's fish program is the protection of the downstream migration of anadromous juvenile fish as they pass through the hydroelectric dams. These systems are typically referred to "bypass systems" and "hold and load" systems. In both cases the migrating fish are guided away from the turbine units and routed into a fish transportation channel. The fish are then either dumped back into the tailrace to continue downstream (bypass) or held in tanks for future transportation to the Pacific Ocean by barge or truck (hold and load).

The hold and load portion of these systems also contain fish sampling and testing facilities comprised of sampling tanks, timed gates to develop statistical data on fish numbers, passive integrated transponder (pit tag) detectors to detect fish previously tagged by fish biologists, and lab buildings for performing biological testing. These hold and load systems require large amounts of flow-through river (raw) water to provide fish with adequate amounts of oxygen and nutrient rich water.

The design of NWW's juvenile fish bypass and hold & load facilities presents many challenges due to the uniqueness of the facilities. One such area is the design of the relatively high flow, low head raw water supply and drainage systems. Like many of the other aspects of these facilities, published design guidance to direct a designer is limited. CEGS 02660 "Water Distribution System", CEGS 02720 "Storm Drainage System", and CEGS 15400 "Plumbing, General Purpose" for example don't specifically apply to the gravity fed supply and drain systems these facilities require. The overall design of these systems is customized using design guidance material from various industry standards and accepted recommended practice. There are many aspects to total pipeline system design, this paper will give an overview of this design process. A comprehensive look at all details is beyond the scope of this paper. It is the intent to indicate the guidance used during design.

Over the past 9 years NWW has designed and installed new juvenile fish facilities on four of our hydroelectric projects. All projects have extensive and complicated raw water systems. The systems have been operating with very few problems, down times, or required retro-fits which helps reinforce our thoughts that the design practice used is sound.

## SYSTEM DESIGN AS A WHOLE

The custom design of these raw water systems begins with a detailed and involved hydraulic analysis of the system, an iterative approach involving tank (or water surface) elevations. Elevations are governed primarily by gravity flow fish transportation hydraulics, a separate yet related part of the system. Required raw water flow rates are determined by District fish biologists based on anticipated fish numbers. At this stage the hydraulic engineer works closely with the fish biologist.

After elevations, flow rates, and preliminary line sizes are established the actual design of the system begins. This too becomes somewhat of an iterative approach between the mechanical and the hydraulic engineer due to actual pipe routing as opposed to how the pipe was hydraulically modeled. At times the actual pipeline involves many more fittings, bends, and even line size changes due to site conditions. Final design must be carefully coordinated primarily with the hydraulic and structural designers to achieve a system that will function properly and not cause interference problems during installation.

## PIPE TYPES

There are many piping materials available today to choose from. Primary consideration in material selection should be given to pipe loadings due to system design pressures, external loads on buried pipe, and loads involved with above grade supported pipe. Another important factor in the design of these fish handling facilities is materials in contact with the raw water, mainly the supply side. Many typically used materials are toxic to juvenile fish. Care must be used in the selection of pipe linings, wetted valve parts, fittings, and all other items that come in contact with the raw water supply system. A partial listing of the materials to be avoided include:

Zinc (galvanizing)

Copper

Brass

Coal Tar

These items limit the designer in pipe lining materials specification for steel pipe and valve selection.

For design of the actual raw water supply and drain piping systems we have utilized a combination of existing standards from industry. Among the standards used are those published by the American Water Works Association (AWWA), The American Iron and Steel Institute (AISI), American National Standards Institute (ANSI), American Society for Testing Materials (ASTM), and the Manufacturers Standardization Society of the Valve and Fittings Industry (MSS). In the subparagraphs that follow are a description of some of the piping materials used in these facilities, some reference standards, and other required considerations.

POLYVINYL CHLORIDE PLASTIC PIPE (PVC)

PVC is used primarily in the fish transportation piping systems due to it’s interior smoothness and the fact that it can be heated and bent for smooth large radius bends. PVC has also been used in the raw water supply system in areas where headloss was a prime concern and for economical reasons. Friction flow coefficients for PVC are lower than most other materials used allowing the hydraulic designer to get a little more flow given the same pipe diameter and head difference. Also in certain sizes and installations, PVC can be an economical alternative to other materials, this requires evaluation on a case by case basis.

For exposed installations PVC must be painted using an alkali resistant primer with latex top coat to prevent pipe damage from the sun’s UV rays. This presents a maintenance concern since these paint systems must be touched up on occasions. Thermal movement in long runs must also be considered. PVC’s length changes approximately 9mm (3/8-inch) in 30.5m (100-ft) for every 5.6 $^{0}$C (10$^{0}$ F) change in temperature. We have also experienced failures due to rapid closures of butterfly valves in PVC lines. This promoted a change in our specifications to have butterfly valves 10mm (4-inches) and larger be supplied with geared operators as opposed to lever operators to reduce the possible speed of operation.

Some of the various types of PVC and reference publications used include:

ASTM D 1785. This standard covers PVC in scheduled sizes (40, 80, and 120) up through 600mm (24-inch) pressure rated for water. This pipe is typically joined using solvent cement or elastomeric seal belled joints, solvent cement fittings, or threaded fittings for Sch 80 and Sch 120.

ASTM D 2241. This standard covers SDR Series PVC in IPS outside diameter sizes up through 900mm (36-inch) pressure rated for water. This pipe is typically joined using solvent cement or elastomeric seal belled joints or solvent cement fittings.

AWWA C 900. This standard covers dimension ratio (DR) Series PVC in cast iron (CI) outside diameter sizes up through 300mm (12-inch) primarily used for underground water distribution systems. This pipe is typically joined using elastomeric seal belled joints.

POLYETHYLENE PIPE (PEP)

PEP is also used primarily for fish transportation piping in the juvenile fish bypass systems. PEP is desired for this purpose because it can be continuously joined by thermal butt fusion. The joint bead is removed on the inside of the pipe joint providing a very smooth, joint free passage for the fish. The bead is removed from the interior by hand if the pipe is large enough for access or by a specially developed machine on the smaller diameters. This pipe can also be bent through large radius bends to eliminate the need for fittings in the fish transport line.

PEP is also used in the raw water supply and drain lines. Like PVC, PEP has smooth interior for better hydraulic conditions and, at times, can be more economical than other materials. When supported overhead a major concern is thermal movement. This pipe’s length changes approximately 28mm (1 1/8-inch) in 30.5m (100-ft) for every 5.6 $^0$C (10$^0$ F) change in temperature. This is about 3 times that of PVC. Another consideration in overhead PEP pipelines is sag of the pipe between supports. This sag is a function of pipe temperature and support spacing.

The actual pipe material should be specified. Items to consider in the material spec include type, grade, treatments for UV protection, and restrictions on the use of recycled material. ASTM D 3350 is a good reference to use when specifying PEP pipe and the material to be used in it’s construction.

Some of the various PEP reference publications used include:

ASTM F 714. This standard covers SDR series PEP in outside diameters from 80mm (3-inch) up through 1200mm (48-inch) pressure rated.  This pipe is typically joined using thermal butt fusion plastic welds or plastic flanges having steel backing rings.

ASTM D 3350.  This standard covers the material to be used in the construction of the pipe according to a cell classification system.  The cell classification system includes information such as density, tensile strength, hydrostatic design basis, and UV stabilizers.  A cell classification should always be included in a PEP specification.

AWWA C 906.  This standard covers dimension ratio (DR) PEP in IPS pipe sizes from 100mm (4-inch) up through 1600mm (63-inch) pressure rated for water service. This pipe is typically joined using thermal butt fusion plastic welds or plastic flanges having steel backing rings.

PRESTRESSED CONCRETE CYLINDER PIPE (PCCP)

PCCP is a pipe type referred to as concrete pressure pipe.  This pipe is typically used for underground water distribution lines. PCCP is offered in two different configurations but is typically manufactured with a steel cylinder having a concrete lining and coating with a pretensioned wire wrapped around the outside coating putting the concrete and steel system in compression. This pretensioned wired is then coated with another concrete layer for corrosion protection.  The steel cylinder acts as the pressure boundary and aids in the beam strength of the pipe.  End connections are also made of steel and are welded to the cylinder providing an o-ring gasket bell and spigot type joint.

PCCP is suitable for pressures up to 3450 kPa (500 psi) and can be designed to withstand specified external loads.  Pressure ratings are achieved by design of the pretensioning wrapped wire system and external loadings are handled primarily by the concrete design.

Some of the various PCCP reference publications and design manuals used include:

AWWA C 301.  This standard covers PCCP in diameters from 400mm (16-inch)up through 3650mm (12-foot), larger sizes are also manufactured based on the concept of this standard.  This standard discusses the design of the pipe only and not the installation

AWWA Manual M9.  This discusses the handling, delivering, laying, field testing, and disinfection of concrete pressure pipe.

## CONCRETE CYLINDER PIPE (CCP)

CCP is also referred to as concrete pressure pipe. This pipe is typically used for underground water distribution lines. CCP is manufactured with a mortar lined steel cylinder having a steel rod wrapped around it under tension followed by the application of a concrete coating. In this system the steel cylinder and mortar lining are placed in compression by the wrapped tension rod. The steel cylinder acts as the pressure boundary and aids in the beam strength of the pipe. End connections are also made of steel and are welded to the cylinder providing an o-ring gasket bell and spigot type joint.

CCP is suitable for pressures up to 2760 kPa (400 psi) and can be designed to withstand specified external loads. Pressure ratings are achieved by design of the pretensioning wrapped wire system and external loadings are handled primarily by the concrete design.

Some of the various CCP reference publications and design manuals used include:

AWWA C 303. This standard covers CCP in diameters from 250mm (10-inch)up through 1520mm (60-inch), larger sizes and higher design pressures have also been manufactured based on the concept of this standard. This standard discusses the design of the pipe only and not the installation.

AWWA Manual M9. This discusses the handling, delivering, laying, field testing, and disinfection of concrete pressure pipe.

STEEL PIPE (SP)

Steel pipe has been used for well over 100 years for many different purposes and is presently offered in a wide variety of sizes, steel types, and reference standards. Steel pipe can be custom designed for most applications or standard off the shelf sizes may be specified depending on the application. Most of the pipe used in the juvenile fish facilities is large enough that standard pipe is not an option. Steel pipe has been used for both raw water piping as well as fish transportation piping. When used for fish transportation, large diameter steel pipe is bent through radiused curves with butt welded joints providing smooth fish passage.

Designing with steel pipe allows many possible variations to be used in support types, coatings, linings, end connections, pressure ratings, and actual sizes as will be discussed throughout the remainder of this paper.

Some of the various SP reference publications and design manuals used include:

AWWA C 200. This standard covers welded straight-seam, spiral-seam, or seamless SP in diameters from 150mm (6-inch) and larger. The standard specifies actual pipe sizes only by reference to other standards as specified by the purchaser. In general the standard covers only the fabrication and testing of the pipe, such as; steel grades, welding requirements, hydrostatic testing, end preparations, and tolerances. Other considerations must be dealt with using other reference publications or custom specifications.

AWWA C 206. This standard covers the field welding of AWWA C200 steel pipe joints. It covers three types of circumferential pipe joints: lap joints, butt joints, and butt-strap joints.

AWWA C 208. This standard provides overall dimensions for fabricated steel pipe fittings. The standard is a dimensional guide only and doesn’t discuss wall thickness, pressure ratings, structural design, or custom design of reinforced fittings. The actual design must be done by the designer or the pipe supplier based on specified design conditions.

ASTM A 53. This is one of the more common standards and covers seamless and welded steel pipe in nominal pipe sizes (NPS) from 3mm ($\frac{1}{8}$-inch) up through 660mm (26-inch) in plain black steel or hot-dipped galvanized. This pipe is intended for mechanical and pressure applications and is acceptable for uses in steam, water, gas, and air lines. When specifying this type of pipe the Grade, Type, and finish should be specifically called out.

ASTM A 134. This standard covers welded straight seam or spiral seam steel pipe in nominal pipe sizes (NPS) 400mm (16-inch) and larger with wall thickness' up to 19mm ($\frac{3}{4}$-inch). When specifying this type of pipe the Grade, size, steel wall thickness, and hydrostatic test pressure should be specifically called out.

ASTM A 135. This standard covers welded steel pipe in nominal pipe sizes (NPS) 19mm ($\frac{3}{4}$-inch) up through 750mm (30-inch) with wall thickness' up to 12.7mm ($\frac{1}{2}$-inch). This pipe is intended for gas, vapor, water, or other liquid service. When specifying this type of pipe the Grade, size, steel wall thickness, purpose of the pipe, and test procedures should be specifically called out.

ASTM A 139. This standard covers welded straight seam or spiral seam steel pipe in nominal pipe sizes (NPS) 100mm (4-inch) up through 2330mm (92-inch) with wall thickness' up to 25.4mm (1-inch). The grades of steel used are pipe mill grades having mechanical properties which differ from standard plate grades. This pipe is intended for gas, vapor, or liquid service. When specifying this type of pipe the Grade, size, steel wall thickness, purpose of the pipe, and hydrostatic test pressure should be specifically called out.

AWWA Manual M11, Steel Pipe - A Guide for Design and Installation. This guide is used by the designer in the design of steel pipe systems. The guide provides principles and procedures which must be used along with good engineering judgment. It may be referenced in the specifications if specific sections and criteria are stated. This guide is one of the better ones to aid the designer in steel pipe design.

AISC Steel Plate Engineering Data; Volume 3. This is a design manual for welded steel pipe and provides design criteria for steel pipe up to 6100mm (240-inch) in diameter, under conditions of internal pressure and external loads most commonly encountered.

American Petroleum Institute (API) is occasionally referenced on pipe submittals, specifically API Spec 5L, Line Pipe.

## GENERAL CONSIDERATIONS FOR STEEL PIPELINE DESIGN

The sections that follow discuss steel pipeline design as it has been performed on our fish facility projects. The design procedures are found in AWWA Manual M11 (M11) using specific requirements in AWWA C 200 unless stated otherwise.

## PIPE SIZE

Size is first governed by hydraulic needs. The actual size and effects on hydraulics are typically iterated during design to achieve the proper hydraulic function along with using available pipe sizes, sizes of pipe appurtenances, and linings. Actual pipe routing may also govern size if space is limited.

## STEEL TYPE

AWWA C 200 allows a number of different grades of steel. The actual grade used will depend on required strength as determined by the pipeline design. In general, AWWA M11 suggests using design stresses not exceeding 50% of the steel’s minimum published yield strength. AWWA C 200 allows steels having minimum yield points ranging from 206.8 MPa (30,000 psi) to 413.7 MPa( 60,000 psi) allowing design stresses of 103.4 MPa (15,000 psi) to 206.8 MPa (30,000 psi), respectively. Availability of the desired grade of steel should be checked prior to specifying it. Also, in some cases higher strength steel grades cost little or no more than the lower strengths so some investigation into costs up front can lead to a more economical design.

## DESIGN PRESSURE

When designing around a certain line pressure or specifying a working pressure for the pipeline and appurtenances, the designer should consider anticipated working pressure, test pressures specified, and any surge or water hammer pressures which may be encountered due to pump cycling or fast valve closures. Note that M11 allows the design stress to be taken at 75% of the minimum yield due to combined transitory surge pressure and static pressure.

## WALL THICKNESS (PRELIMINARY)

Steel pipe wall thickness must be specified. Generally wall thickness is governed by a combination of loads. To determine the final required wall thickness, design pressure loads must be properly combined with external loads for buried pipe and a variety of loads encountered on pipe supported above grade. Vacuum pressures must also be considered if they are anticipated.

Required wall thickness due to pressure loads is found using:

$$t = \frac{pd}{2s}$$

t = wall thickness (in)
p = pressure (psi)
d = pipe OD (in)
s = allowable stress (psi)

The minimum allowable thickness required for handling of any pipe is:

$$t = \frac{D}{288}$$ Up to 1370mm (54-inch) ID

$$t = \frac{D\%20}{400}$$ Greater than 1370mm (54-inch) ID

D = pipe diameter
t = wall thickness

Pipe wall thickness shall never be less than 14 gauge.

As a quick reference, TABLE 4-2 of M11 publishes pipe wall stress as a function of pipe size, wall thickness, and working pressure.

EXTERNAL LOADS ON BURIED PIPE

External loads on buried pipe are generally a combination of earth loads from backfill and live loads from traffic.  In some cases there may be concentrated loads on the buried pipe due to heavy equipment traveling over the pipe during the construction process for instance.  M11 provides methods to analyze both concentrated loads and typical earth and normal traffic loads. The effect of the external loadings on the pipe is a function of certain soil conditions and installed procedures.  These items should be discussed with the Civil/Soils Engineer.

Pipe wall thickness is determined from strength needs to limit deflection and prevent buckling.

PIPE SUPPORTED ABOVE GRADE

Stresses and loads on pipelines supported above grade which must be considered in pipe wall determination are:

Localized stress at support

Flexure stress in pipe span

Ring stress due to internal pressure

Weight of linings and coatings

Weight of fluid in pipe

Weight of pipe wall itself

Stress risers caused by pipe half-full condition

Thrust loads

Thermal stresses

Seismic loads

Snow and wind loads

Point loads due to valves or couplings

PROTECTIVE COATINGS AND LININGS

Specifying a protective coating and lining for steel pipe is the first defense in corrosion control.  Corrosion control is a science in itself and other methods will not be discussed here. There are many good publications and reference materials on corrosion control available, too many to list here.

Coating selection should consider the compatibility with the installed environment, potential damage caused by handling and installing, and ease of field repair methods to insure a good long term installed protective coating.

Lining selection should consider fluids to be transported, smoothness for hydraulic flow resistance, ease of field repair, and toxicological requirements for fish water supply or potable supply.

Before specifying a lining system, the designer should check on pipe size restraints in the proposed reference specification. Many lining systems are limited to larger pipe sizes allowing access for repair.

Some of the more common steel pipe coating and lining reference publications used include:

AWWA C 203.  Coal-Tar Protective Coatings and Linings for Steel

Water Pipelines, Enamel and Tape, Hot-Applied. This system is toxic to fish, use as coatings and drain system linings only in fish facilities.

AWWA C 205. Cement-Mortar Protective Lining and Coating for Steel Water Pipe. This system is used extensively for below grade coatings and linings in fish facility design.

AWWA C 209. Cold-Applied Tape Coatings for the Exterior of Special Sections, Connections, and Fittings for Steel Water Pipelines.

AWWA C 210. Liquid Epoxy Coating Systems for the Interior and Exterior of Steel Water Pipelines. This system has been specified for the interior of large fish transportation steel pipelines having butt welded joints. Pipeline must be large enough to allow access for interior joint repair.

AWWA C 213. Fusion-Bonded Epoxy Coating for the Interior and Exterior of Steel Water Pipelines. This is a high performance and expensive system. Field repair is very specialized also.

AWWA C 214. Tape Coating Systems for the Exterior of Steel Water Pipelines. This is a factory applied three-layer coating system.

AWWA C 602. Cement-Mortar Lining of Water Pipelines - In Place. This standard discusses the mortar lining of pipelines in place including both new and existing pipelines.

Paint System 16. This is used for pipe coating on above grade pipe having atmospheric exposure and receiving a colored finish.

Paint System 21. This is used for above grade pipe exposed to a more harsh environment, possibly having the exterior submerged or constantly wetted.

PIPE JOINTS

There are many pipe joints available.  Things to consider when specifying joints are:

Required flexibility

Dissimilar metals isolation for corrosion protection

Restraint required due to pressure/thrust loads

Thermal movement allowance

Lining and coating repair

Installation tolerance

Seismic isolation

PIPE TESTING

Specific testing procedures should be included in every pipeline design.  It is a good idea to have test procedures submitted for approval along with the pipeline layout drawings in order to alleviate problems encountered after the pipe is installed. Specified testing procedures should be detailed including length of test, allowable leakage or pressure loss, cycling of valves, and methods of test water disposal.

## STEEL PIPE SUPPORTED ABOVE GRADE

The previous section mentioned items to look for when designing a steel pipeline supported above grade.  Chapter 7, “Supports for Pipe” of AWWA Design Manual M11 is a good reference when designing these types of systems.  M11 also references many good related publications on this topic.

WALL THICKNESS (FINAL)

Preliminary wall thickness for steel pipe was discussed previously.  The final wall thickness required is the heavier wall as determined from either the preliminary design or the detailed stress design.  The detailed stress design must look at critical stress areas on the pipeline.  The two areas of concern are the stress at the point of support and the stress at midspan.

## Stress at the Support

In general there are two methods of supporting large diameter thin wall steel pipe, saddle supports or ring-girders. Ring-girders typically allow longer spans for pipe due to their higher load carrying capability than saddles. Ring-girders stiffen the circular section of the pipe wall at the highly loaded support area allowing it to perform as a beam. Saddle supports cause high localized stresses in the unstiffened steel wall at the tips and edges of the saddle support. In either case, total stress at the support is a combination of stresses and is typically the governing stress as opposed to the stress at midspan, beam stress. Equations referenced in the paragraphs that follow are those out of M11.

For pipe with restrained ends supported by saddles the maximum stress at the support is a combination of the following stresses:

Localized stress at the saddle (reaction stress), Eq (7-1)

Flexure stress at support plus 25% of hoop stress due to internal pressure (beam type and pressure stress), Eq (7-2)

For pipe supported on ring-girders the maximum stress in the pipe shell at the support is a combination of the following stresses:

Combined maximum longitudinal stress (beam type stress), Eq (7-6)

Maximum rim bending stress (internal pressure stress), Eq (7-7)

Ring-girder design is an iterative approach due to the nature of the stress in the girder as it relates to the stress in the pipe wall, as one goes up the other goes down.

## Stress at Mid Span and Final Wall Thickness Determination

Stress at mid span, or beam type flexure stress, is also a concern and may be the stress which governs wall thickness. As mentioned above, greater spans can be achieved with the use of ring girder supports. The ring girder maintains the pipe’s circular cross section allowing it to better act as a typical beam. Otherwise, large diameter thin wall pipe tends to flatten out at the highly loaded supports causing it to loose some of it’s sectional modulus. The stress at mid span is calculated by applying the proper loads and the use of typical beam equations. Loads used on overhead supported pipe were previously discussed. Final steel pipe wall thickness is then determined by comparing all stresses found in the final analysis and providing for worst case.

## CONCLUSION

There are many considerations in the design of piping systems and even more so for facilities handling juvenile fish. The designer should take a systematic approach to ensure all details are covered in order to provide a functional, low maintenance, economical, and long life water supply and drain system. Iterative approaches are encouraged in the design of pipelines supported above grade. Spans can be manipulated by changing support types allowing longer spans requiring fewer structural supports.

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